# Pediatric trauma: differences in pathophysiology, injury patterns and treatment compared with adult trauma

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Although multiple trauma remains the leading cause of death among children, fewer resources and less attention have been directed to treatment of the injured child than to treatment of the injured adult. Insufficient training of medical personnel and hence lack of expertise in the management of injured children are factors contributing to disability and death in such children. Although the principles of resuscitation of injured children are similar to those for adults, appreciation of the differences in cardiorespiratory variables, airway anatomy, response to blood loss, thermoregulation and equipment required is essential for successful initial resuscitation. Cerebral, abdominal and thoracic injuries account for most of the disability and death among injured children. Cerebral damage may be due to secondary injuries to the brain and is potentially preventable. The need to preserve the spleen in children complicates the management of abdominal trauma. Although children usually have large cardiorespiratory reserves, they are likely to need airway control and ventilation with thoracic injuries. The psychologic effect of trauma may pose long-term problems and needs close follow-up.

Les polytraumatismes restent la cause de décès la plus importante chez l'enfant; mais en ce qui le concerne on s'est moins penché sur leur traitement et on y a affecté moins de ressources que pour ce qui regarde l'adulte. La formation insuffisante des médecins et le manque de compétence qui en résulte dans le traitement des enfants blessés jouent un rôle dans la survenue d'infirmités et de décès parmi eux. Si les principes de la réanimation sont les mêmes à tout âge, il faut connaître les différences entre l'enfant et l'adulte dans les normes cardiorespiratoires, l'anatomie des voies aériennes, les effets de l'hémorragie, la thermorégulation et l'appareillage si on veut réaliser d'emblée avec succès la réanimation de l'enfant. La plus grande partie des infirmités et des décès chez lui résultent de traumatismes cérébraux, abdominaux et thoraciques. Les lésions cérébrales, dans la mesure où elles peuvent être secondaires, sont susceptibles de prévention. Le traitement des traumatismes abdominaux se complique du besoin de préserver la rate. Si l'enfant possède de fortes réserves cardiorespiratoires, les traumatismes thoraciques chez lui nécessitent volontiers la surveillance des voies aériennes et la respiration artificielle. Enfin, les effets psychologiques de l'accident peuvent poser de sérieux problèmes à longue échéance et exiger qu'on les suivre de près.

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Accidents have been the leading cause of death among children aged 1 to 14 years for the last 40 years.[1,2] When prevention, our first priority, has failed, a well-trained, responsive emergency medical system using a systematized approach to the treatment of injuries is essential.

Developments in the assessment and management of pediatric trauma have lagged behind those of adult trauma for several reasons. Since the number of critically ill children is small, fewer resources are devoted to establishing emergency medical systems for this age group.[3] In addition, training in the care of injured children is less widespread than comparable training and experience oriented toward adults.[4] Many rescue units in the United States do not even carry appropriate pediatric resuscitation equipment or medications.[5] These deficiencies are not unique to the United States. Informal discussions at scientific meetings with paramedics and emergency department directors from Canada have revealed a similar trend and philosophy in planning emergency medical systems here.

On the basis of evaluations of the few courses offered in pediatric advanced life support (ALS), most physicians would acknowledge venous access as an important problem in resuscitation of the injured child. However, the developmental changes in cardiorespiratory variables, differences in drug dosages, injury patterns unique to children and concern for the emotional well-being of the growing child[2,6] are not fully appreciated. This partly relates to the fact that current textbooks of emergency medicine and ALS courses focus on adult trauma and devote little space to injuries in children.[7-9] However, about 90% of pediatric emergency visits are to the emergency department of general hospitals,[10] and up to 50% of pediatric patients are undermedicated when seen on referral.[11]

In 1966 Izant and Hughby[12] stated that "childhood trauma is one of the poorest understood and most serious social, economic, and medical phenomena of current times". This statement remains painfully true today. The Ad Hoc Committee on Care of the Critically Ill Child of the American Academy of Pediatrics noted that the death rate among trauma patients is higher for children than for adults and that the education of paramedics and emergency department personnel may not be adequate to provide proper management of injured children.[13]

The principles of resuscitation of trauma patients have been thoroughly discussed elsewhere.[7-9] In this article we point out the unique anatomic and physiologic differences and injury patterns in children and their clinical relevance to management.

## Airway and breathing

Management of a child's airway depends on knowledge and understanding of the anatomic and physiologic differences as a function of age. Apart from size differences, the child's airway has a narrow subglottic area, the larynx is anterior and cephalad,[14,15] the epiglottis is omega shaped and attached to the vocal cords at an acute angle,[15] the trachea is more compliant, the gums are more vascular and bleed easily, and the deciduous teeth are poorly anchored and easily dislodged compared with the permanent teeth.[14] The relatively large head–body ratio of the child, the compliance of the trachea and the large tongue relative to the oral cavity may pose some difficulty for those working primarily with adults.[14] The child's respiratory gas exchange may also be compromised by gastric dilatation, which is commonly seen after trauma in children.

Control of the airway involves placing the child in the "sniffing" position.[14,15] The neck should be slightly flexed on the chest and the head slightly extended on the neck. The occiput of the head should first be raised above the level of the shoulders by placing a folded towel or hand under the child's head. Then one hand should be placed at the angle of the mandible and gentle forward pressure applied (jaw thrust [Fig. 1A]) or the chin pulled forward (chin lift [Fig. 1B]). Because the trachea is very compliant, overextension of the head on the neck may result in upper airway obstruction. To prevent the tongue from obstructing the posterior pharynx, an oral airway is necessary in most cases.

If intubation of the airway is needed, a selection of laryngoscope blades and endotracheal tubes, both cuffed and uncuffed, should be readily available. Cuffed endotracheal tubes should rarely be used in children less than 8 years of age.[16] Table 1 provides baseline cardiorespiratory values in children.[17,18] Table 2 provides guidelines for selecting airway support equipment, Table 3 guidelines for choosing an appropriately sized endotracheal tube and Table 4 a list of supplemental equipment that may be needed for resuscitation.[16]

## Cervical spine control

Cervical spine injuries are rare in children under 12 years old because of the greater mobility and elasticity of the cervical spine.[19] However, an injury should be suspected in any child who has significant head or facial trauma, is unconscious or complains of neck pain. In such cases proper immobilization (with sand bags, boards or a cervical collar), without inline traction,[20] should be used; in some cases the cervical spine may be unstable, and inline traction would disrupt the fragments further and worsen the injury. In children with unexplained refractory shock the possibility of spinal cord injury with spinal shock should be considered. Spinal cord injury should not be diagnosed or ruled out on the basis of radiograph-

ic evaluation alone, since in up to 67% of children with such an injury no radiographic abnormality is demonstrated.[21] However, they usually have transient paresthesia, numbness or paralysis after injury.[21] Interpretation of the cervical spine radiograph is more difficult in the child than in the adult since several variants of normal are commonly confused with the effects of trauma.[22] Although there is no consensus on the management of the child with a possible cervical spine injury, roentgenography of the lateral cervical spine is warranted in patients with multiple trauma, a history of neck trauma, or cervical pain or tenderness and those who have abnormal mental or neurologic status.[23] The strategy outlined in Fig. 2 is a reasonable approach to these patients.

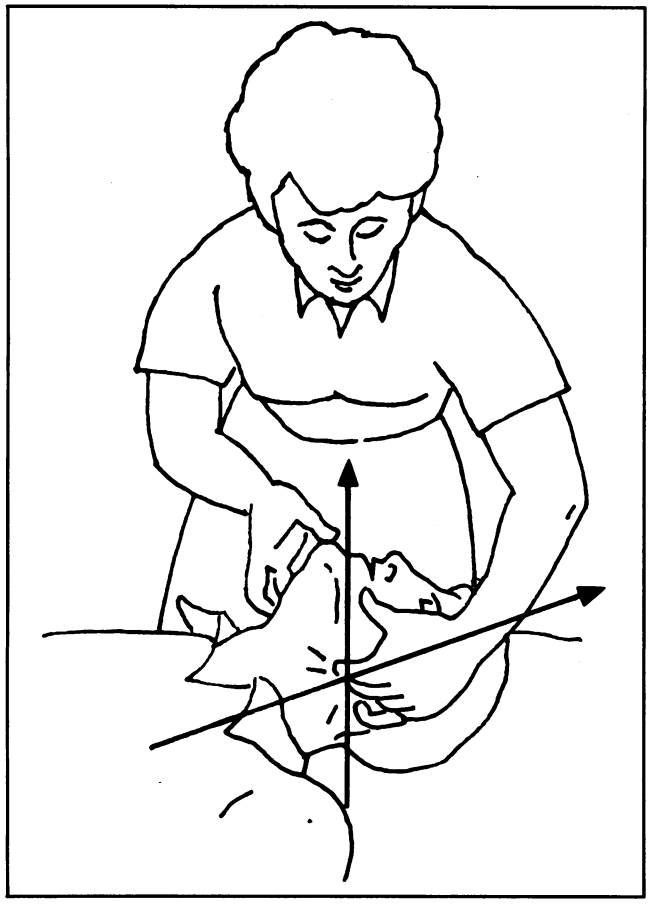

**Fig. 1A: Jaw-thrust maneuver for maintaining airway patency.**

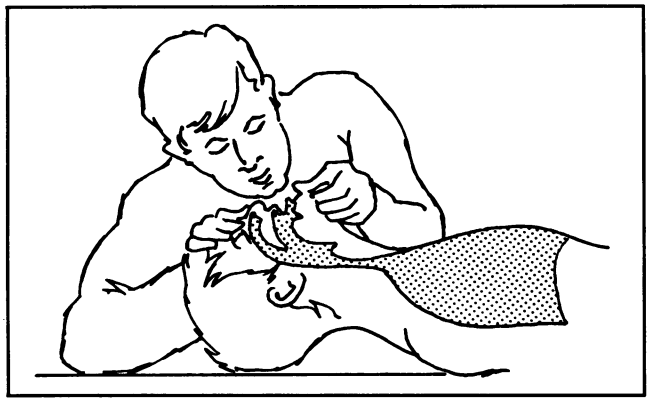

**Fig. 1B: Chin-lift maneuver for maintaining airway patency.**

## Circulation

As early as 1919 it was noted that "while low blood pressure is one of the most constant signs of shock, it is not the essential thing, let alone the cause of it. We have focused our attention far too much on blood pressure."[24] This statement is especially true in the child, since children may maintain their blood pressure until late in their clinical course.[6] Any child who presents with hypotension secondary to hypovolemia has usually lost at least 25% and sometimes as much as 50% of the total blood volume.[25] It is now well recognized that the central factor in all patients (children and adults alike) with shock is a generalized state of inadequate tissue perfusion resulting in impaired cellular respiration.[24,25] However, there are several differences between the pediatric and the adult trauma patient.

First, indices of blood pressure, pulse rate and respiratory rate are age dependent (Table 1), and drug dosages and intravenous infusions are weight related in the child, whereas in the adult more standard therapy may be given. There is also a precariously thin margin for error in the recognition and treatment of shock in the child. Because of a smaller total blood volume, children may lose the same amount of blood as an adult with more serious consequences. The evaluation of infants for signs of shock may be even more difficult than the evaluation of older children and adults.[26] In infants shock may manifest as hyperventilation or hypoventilation, skin mottling, erratic cardiovascular measures, glucose intolerance or metabolic instability.[26] In view of the difficulties in the clinical assessment of shock,

Table 1: Baseline cardiorespiratory values in children

| Variable | Infants (< 2 yr) | Preschoolers (2–4 yr) | School age (5–16 yr) |
|---|---|---|---|
| Respiratory rate/min[17] | 20–40 | 16–30 | 14–20 |
| Pulse rate, beats/min[17] | < 140 | < 120 | < 100 |
| Systolic blood pressure, mm Hg | 80 + (2 × age [yr] )[18] | | |
| Diastolic blood pressure, mm Hg | 2/3 systolic blood pressure[18] | | |
| Blood volume, ml/kg | 85 | | |

Table 2: Guidelines for selecting airway support equipment

| Equipment | Age | | | | |
|---|---|---|---|---|---|
| | Newborn | 1–11 mo | 12–35 mo | 3–11 yr | >11 yr |
| Laryngoscope blades* | Miller 0 | Miller 1 | Wis Hipple 1.5 | Miller 2 | Miller 2 or McIntosh 2 or 3 |
| Oropharyngeal airway† | Portex 00 (5 cm) | Portex 0 (6 cm) | Portex 1 (7 cm) | Portex 1 (7 cm) | Portex 2 (8 cm) |
| Masks | Rendel Baker 0‡ Laerdal 00* | Rendel Baker 1‡ Laerdal 0/1* | Rendel Baker 2‡ Laerdal 0/1* | Rendel Baker 3‡ Laerdal 2* | Adult sizes |

*Armstrong Medical Industries of Canada, Scarborough, Ont.
†Sims, Markham, Ont.
‡Trudell Medical, London, Ont.

urine output should be monitored continuously in all children as an index of renal perfusion and circulatory status. An hourly output greater than 1 ml/kg in children and 2 ml/kg in infants indicates good renal blood flow and hence adequate circulatory volume.[25] As a general guideline, hypovolemic shock is rarely attributable to head injury alone, except in children with large scalp lacerations, open skull fractures with dural sinus tears, or hydrocephalus and severe intraventricular bleeding.

## Thermoregulation

The injured child may be exposed to environmental temperature at the scene of the accident and may arrive at the hospital in a hypothermic state. In addition, because of poor homeostatic thermoregulatory responses, infants do not tolerate cold examination rooms, radiology rooms and intravenous fluids well.[27] Rapid heat loss occurs because of the larger body surface area in relation to weight and may complicate shock or even render it refractory.[24] The child's temperature should therefore be measured regularly, and an appropriate pediatric radiant warmer may be necessary to maintain body temperature when the child is exposed for the initial survey and resuscitation.

Table 3: Guidelines for selecting appropriately sized pediatric endotracheal tube

| |
|---|
| Internal diameter: 4.0 + (age [yr] ÷ 4) mm |
| Always have tubes one size smaller and one size larger available |
| Do not use cuffed tubes in children under 8 years of age |
| Internal diameter of tube is approximately equal to diameter of fifth finger of child |
| Other equipment |
| Stylets (6 and 14 French) |
| Suction catheters (6 to 14 French) |
| Magill forceps (neonatal, pediatric, adult sizes)* |
| Yankauer Tonsil Suction (neonatal, pediatric,† adult‡) |

*Armstrong Medical Industries of Canada.
†Trudell Medical.
‡Bard Canada Inc., Mississauga, Ont.

## Venous access

Difficulty in establishing venous access in the child has been recognized as the limiting step in pediatric resuscitation.[28] The most commonly used method, peripheral venipuncture, may be very difficult in a chubby infant with decreased vascular volume. The time required for completion of a venous cutdown (1 to 90 minutes), even by experts, makes its use as a first choice in an emergency unrealistic for most clinicians.[29]

Intraosseous infusion can be used when venous cannulation is difficult and when lifesaving fluids or medications need to be rapidly introduced into the circulation.[30,31] This route has been used to infuse a number of fluids, including blood, plasma, saline, dextrose and, more recently, cardioresuscitative medications.[31,32] The intraosseous route provides relatively easy vascular access, requires very little skill and is remarkably free of complications.[32] Con-

Table 4: Supplemental equipment[16]

| Equipment | Age | | | | |
|---|---|---|---|---|---|
| | Newborn | 1–11 mo | 12–35 mo | 3–11 yr | > 11 yr |
| Nasogastric tubes, French | 12 | 12 | 12 | 12 | 12 |
| Chest tubes, French | 10–14 | 12–18 | 14–24 | 20–32 | 28–38 |
| Foley urinary catheters, French | 5–8 | 8 | 10 | 10–12 | 12 |
| Cervical collars | | Small | Small | Small | Medium |
| Catheters (intravenous and intraosseous) | | | | | |

traindications include gross infection or fracture at the intended site of insertion.[32]

Although any large-bore metal needle with a stylet may be used, bone marrow needles and recently developed intraosseous needles are easier to insert. The preferred site is the flat tibial surface approximately 2 cm below the tibial tubercle or the anterior superior iliac spine.[30-32] The skin at the site of puncture is cleaned with alcohol, and one inserts the needle using firm pressure and a rotary motion. The marrow cavity is entered when a loss of resistance to pressure is felt. Correct placement is confirmed when the needle is firmly fixed in the bone and aspiration of marrow into a syringe under negative pressure is demonstrated. Recent studies have shown that intraosseous infusion is a rapid and effective alternative to central and peripheral routes in cardiac arrest.[33] It has been used in the prehospital setting in children.[34] Although infusion into the growth plate has not been associated with significant growth defects,[35] it is prudent to avoid the growth plate if at all possible, since the potential for growth impairment exists.

## Injury patterns

The unique characteristics of head, abdominal and chest injuries in children are important because these injuries account for most of the disability and death among injured children.[36]

### *Head injuries*

Head injuries are very common in children and are the leading cause of disability and death. At least 80% of children dying with multiple trauma have significant head injuries, compared with 50% of adults.[37] Head injuries are more common in children because of several factors: the head-body ratio is much greater; the brain of the child, especially in early childhood, is less myelinated and hence more easily injured; and the cranial bones are thinner and afford less protection to the brain.

Children with severe head injury are more likely

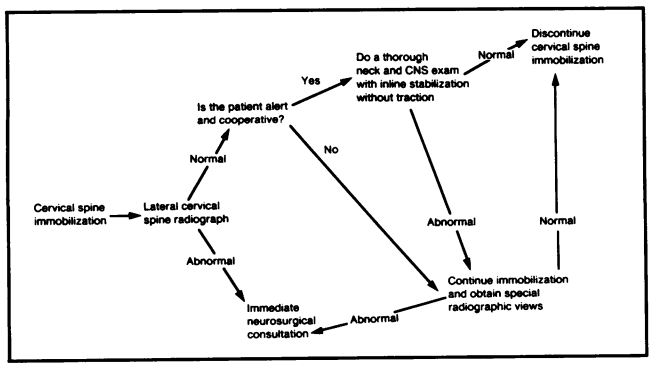


**Fig. 2: Algorithm for management of child with possible cervical spine injury. CNS = central nervous system.**

than adults to have intracranial hypertension (80% v. 40% to 50%).[37] They are also more prone to a unique form of brain injury termed "malignant brain edema",[38] which is due to brain hyperemia occurring shortly after the injury and is distinct from cytotoxic edema, which may develop later. Children also have a lower incidence of mass lesions than adults (30% v. 40% to 50%).[39]

The predisposition to cerebral hyperemia and resulting intracranial hypertension makes children more vulnerable to secondary brain injury. Since a favourable outcome depends on the prevention of secondary brain injury, children with head injury do substantially better when therapy to decrease hyperemia and brain edema is started early.[40] Since carbon dioxide is a cerebrovasodilator,[41] respiratory support and hyperventilation to an arterial partial pressure of $CO_2$ of 25 to 35 mm Hg should be started early to achieve cerebrovasoconstriction and decrease brain hyperemia and edema.[42] Prompt resuscitation (airway control, hyperventilation, adequate oxygenation and treatment of shock) is mandatory before neurologic examination and is more critical than rushing the child to the nearest neurosurgeon.

Elevating the head of the bed 30° to 45°, minimizing stimulation and aggressively treating seizures are very important measures.[37] Therapy with a diuretic (furosemide or mannitol) should be started only in patients with suspected intracranial hypertension who are unresponsive to hyperventilation and are not in shock.[40] Since children with head injury may have various degrees of neurologic dysfunction and greater than 90% have mild injuries,[43] management guidelines should be based on the risks of intracranial sequelae.

The Glasgow Coma Scale[44] (Table 5) evaluates the level of consciousness after head injury and is an important factor influencing treatment and outcome.[39,45] Patients with a score of less than 10 or a

Table 5: Glasgow Coma Scale[44]

| | |
|---|---|
| Eye-opening response | |
| Spontaneous | 4 |
| To speech | 3 |
| To pain | 2 |
| None | 1 |
| Verbal response | |
| Oriented | 5 |
| Confused conversation | 4 |
| Inappropriate words | 3 |
| Incomprehensible sounds | 2 |
| None | 1 |
| Best upper limb motor response | |
| Obeys commands | 6 |
| Vocalizes | 5 |
| Withdraws | 4 |
| Abnormal flexion | 3 |
| Extensor response | 2 |
| None | 1 |

decrease of more than 2 points should be considered as having a severe head injury and requiring early intervention. In children less than 2 years of age with limited verbal skills a full verbal score should be assigned if the infant is able to cry after stimulation.[46] To our knowledge, several modifications of the Glasgow Coma Scale for this age group have not been validated.

### *Abdominal injuries*

Abdominal injuries are a frequent cause of accidental death in children.[36] Most commonly, blunt abdominal trauma is involved;[47] it may be very difficult to evaluate because physical findings may be minimal despite serious injury,[48] and concomitant multiple injuries may divert attention from abdominal injury. The need to preserve the spleen, especially in the younger child, also complicates management.[49-51] Injuries to solid organs predominate, possibly owing to the flexible rib cage and less developed abdominal musculature in children.[52] Trivial trauma may also result in severe intra-abdominal injury, especially in children with congenital malformations such as hydronephrosis.

Serial abdominal examinations by an experienced examiner is the most important clinical measure in assessing the magnitude of intra-abdominal injury. Very few children bleed so suddenly and massively that surgery is mandatory on arrival at hospital.[50] Those who do are usually brought to the emergency department in shock, and after urgent resuscitation the abdomen becomes distended.[50] The cardinal findings in cases of severe intra-abdominal bleeding are distension and tenderness. Most patients with blunt abdominal trauma and some with penetrating trauma can be managed nonoperatively. However, this should be done only after surgical consultation and depends on the availability of adequately trained staff and a blood supply.

The nonoperative management of spleen and liver injuries[47] in children has caused clinicians to change their philosophy as to the need for abdominal paracentesis. It should be considered in the following patients if they are hemodynamically stable, especially if abdominal computed tomography is not available: those with altered pain responses (e.g., those who are unconscious or have drug-related central nervous system depression), those undergoing anesthesia for nonabdominal surgery and those with unexplained shock responsive to therapy.[53] The results of abdominal paracentesis may be negative despite significant bleeding in the retroperitoneal space. However, abdominal distension and volume compromise will be apparent on repeat examinations. Palpation of the abdomen should always be gentle and kept to a minimum if splenic or hepatic trauma is diagnosed.

### *Thoracic injuries*

Thoracic injuries occur frequently with head or abdominal injuries and are associated with a high death rate.[47] The pattern of injuries in children is different from that in adults in the following ways.

- The elasticity and resilience of the chest wall make fractures of ribs and sternum and flail chest less common than in adults.[54]
- Severe parenchymal thoracic injuries may be present with minimal or no signs of external trauma and with a normal admission chest x-ray film.[53]
- Great mobility of the heart and mediastinum may produce dislocation of the heart, transection or angulation of the great vessels, tracheal compression and angulation etc.[54]
- The tremendous cardiac and pulmonary reserve of the healthy child may obscure the presence of severe lesions such as myocardial or pulmonary contusion and diaphragmatic rupture. However, the child's high metabolic needs leave little time for deliberation and consultation when there is hypoxemia or hypotension.[55]

The approach to resuscitation of these patients is similar to that in adults. However, because of the above factors, children are more likely to need airway control and assisted ventilation.[55]

Traumatic asphyxia occurs almost exclusively in children because of their flexible thorax and the absence of valves in the superior and inferior cava.[56] Direct, sudden compression of the compliant thoracic cage against a closed glottis causes a sudden dramatic rise in intratracheal and intrapulmonary pressures and concomitant temporary vena cava obstruction, with capillary extravasation and hemorrhage in the brain and other organs. Children may present with disorientation, loss of consciousness, seizures, cervical and facial cyanosis, subconjunctival hemorrhage, vascular engorgement and petechiae of the chest, head and neck, acute hepatomegaly or respiratory distress. Therapy consists of removing the underlying causes and treating any resulting complications.

## The abused child

In treating injured children the physician must be prepared to consider child abuse as an explanation of the injuries. Prompt recognition of child abuse is crucial, as there is a definite tendency to repeated attacks, often with increased severity. Readers are referred to pertinent reviews for further information on this subject.[57-60]

## Psychologic problems in childhood trauma

Management of the psychologic problems in trauma is often overlooked in the chaotic milieu of

the emergency department. Fear of doctors and strange faces, separation from their parents, painful procedures and poor understanding of their injuries put children under enormous psychologic strain. Children are not mature enough to cope with these stresses[61] and may exhibit behaviour regression. They may also suffer long-term psychologic problems long after the physical injuries have healed. The physician who understands these characteristics will attempt to win the child's confidence with gentleness, a nonthreatening approach and repeated explanations and by having the parents around as long as possible. Also, forewarning of painful procedures allows the child time to prepare for the pain, which decreases its intensity. Inadequate or inappropriate care after the injury may affect the quality of the child's life for years to come.[61]

## Conclusions

With appropriate initial resuscitation and follow-up care, most injured children can be expected to have a good outcome. Recognition of the fact that children are different from adults and preparation for the therapeutic implications of these differences are the important first steps in management. With appropriate preparation and education, the reward will be successful resuscitation of the injured child.

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## *Conferences*

***continued from page 26***

**May 22-24, 1990:** 3rd S.M. Dinsdale International Conference on Rehabilitation
Ottawa Congress Centre
Education Department, Rehabilitation Centre, 505 Smyth Rd., Ottawa, Ont. K1H 8M2; (613) 737-7350, ext. 602; FAX (613) 737-7056

**May 25, 1990:** 1st Annual National Rehabilitation Nursing Conference and 2nd Annual Meeting of the Canadian Association of Rehabilitation Nurses
Rehabilitation Centre, University of Ottawa
Education Department, Rehabilitation Centre, 505 Smyth Rd., Ottawa, Ont. K1H 8M2; (613) 737-7350, ext. 602; FAX (613) 737-7056

**June 3-6, 1990:** Canadian Dietetic Association Annual Conference: "Dare to Grow"
Ottawa Congress Centre
Joan Wyatt, chair, Conference Planning Committee, Royal Ottawa Rehabilitation Centre, 505 Smyth Rd., Ottawa, Ont. K1H 8M2; (613) 737-7350, ext. 544

**June 3-6, 1990:** Choices — Long-Term Care in the 90s — a Decade of Change (sponsored by the Alberta Long Term Care Association and the Canadian Long Term Care Association)
Calgary Convention Centre
Alberta Long Term Care Association, 1010 CN Tower, 10004-104 Avenue, Edmonton, Alta. T5J 0K1; (403) 421-1137, FAX (403) 426-0479

**June 7-9, 1990:** American Society for Bariatric Surgery 7th Annual Meeting
Royal York Hotel, Toronto
Dr. Thomas J. Blommers, executive manager, American Society for Bariatric Surgery, Box 639, 633 Post St., San Francisco, CA 94109

**June 12-15, 1990:** Canadian Hospital Association Annual Conference: Caring for Medicare
Centennial Auditorium and Holiday Inn, Saskatoon
Conferences, Canadian Hospital Association, 100-17 York St., Ottawa, Ont. K1N 9J6; (613) 238-8005

**June 15-19, 1990:** Canadian Anaesthetists' Society 47th Annual Meeting
Hyatt Regency Hotel, Vancouver
Ann Andrews, executive director, Canadian Anaesthetists' Society, 187 Gerrard St. E, Toronto, Ont. M5A 2E5; (416) 923-1449

**June 24-29, 1990:** 3rd International Conference on Emergency Medicine (hosted by the Canadian Association of Emergency Physicians, in association with the American College of Emergency Physicians, the Australian College for Emergency Medicine and the Casualty Surgeons Association of Great Britain)
Royal York Hotel, Toronto
Continuing Education, Faculty of Medicine, University of Toronto, Medical Sciences Building, Toronto, Ont. M5S 1A8; (416) 978-2718

***continued on page 39***